Lake and wetland restoration: a tale of three systems

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Annis Water Resources Institute, GVSU


SCIENCE MATTERS

Today's Presentation

- Muskegon Lake Area of Concern
  - Muskegon Lake
  - Bear Lake muck fields
- HABs
- Spring Lake Restoration

Areas


Peninsula Harbor
Jackfish Bay
Nipigon Bay
Thunder Bay
Torch Lake
Deer Lake - Carp Creek/River
St. Louis Bay/River
Manistique River
Menominee River
Fox River/ Lower Green Bay
Sheboygan River
Milwaukee Estuary
White Lake
Waukegan Harbor
Muskegon Lake
Kalamazoo River
Grand Calumet River/ Indiana Harbor Canal
Saginaw Bay
Maumee River
River Raisin
Detroit River
Rouge River
Black River
Ashtabula River
Cuyahoga River
Presque Isle Bay
Hamilton Harbour
Buffalo River
Niagara River
Eighteen Mile Creek
Oswego River
St. Lawrence River (Cornwall/ Massena)

BUIs for Muskegon Lake

Impairments	
Restrictions on fish and wildlife consumption	Beach Closings
Degradation of Fish and Wildlife Populations	Groundwater Contamination
Degradation of Benthos	Degradation of Aesthetics
Restrictions on Dredging	Eutrophication and Undesirable Algae
Loss of Fish and Wildlife Habitat	

Muskegon Lake

Parameter	Muskegon
Surface Area (km^2)	16.8
Mean Depth (m)	7.1
Max. Depth (m)	23
HRT (d)	21
Mean TP (µg/L)	~25
Mean Chl *a* (µg/L)	~7
Trophic status	Meso/Eutrophic


Location of AWRI
Muskegon Lake
Lake Michigan

Muskegon 1889

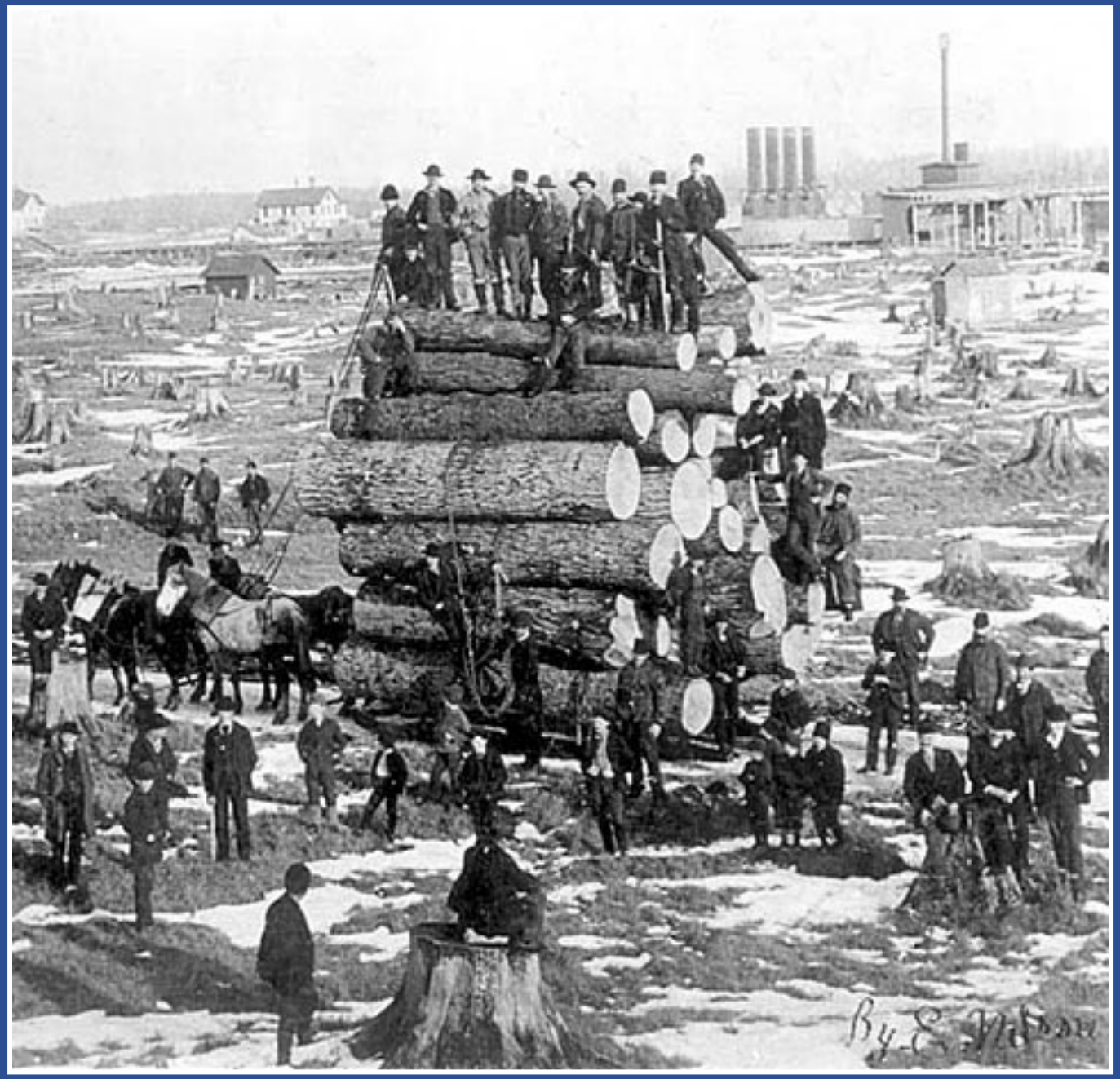
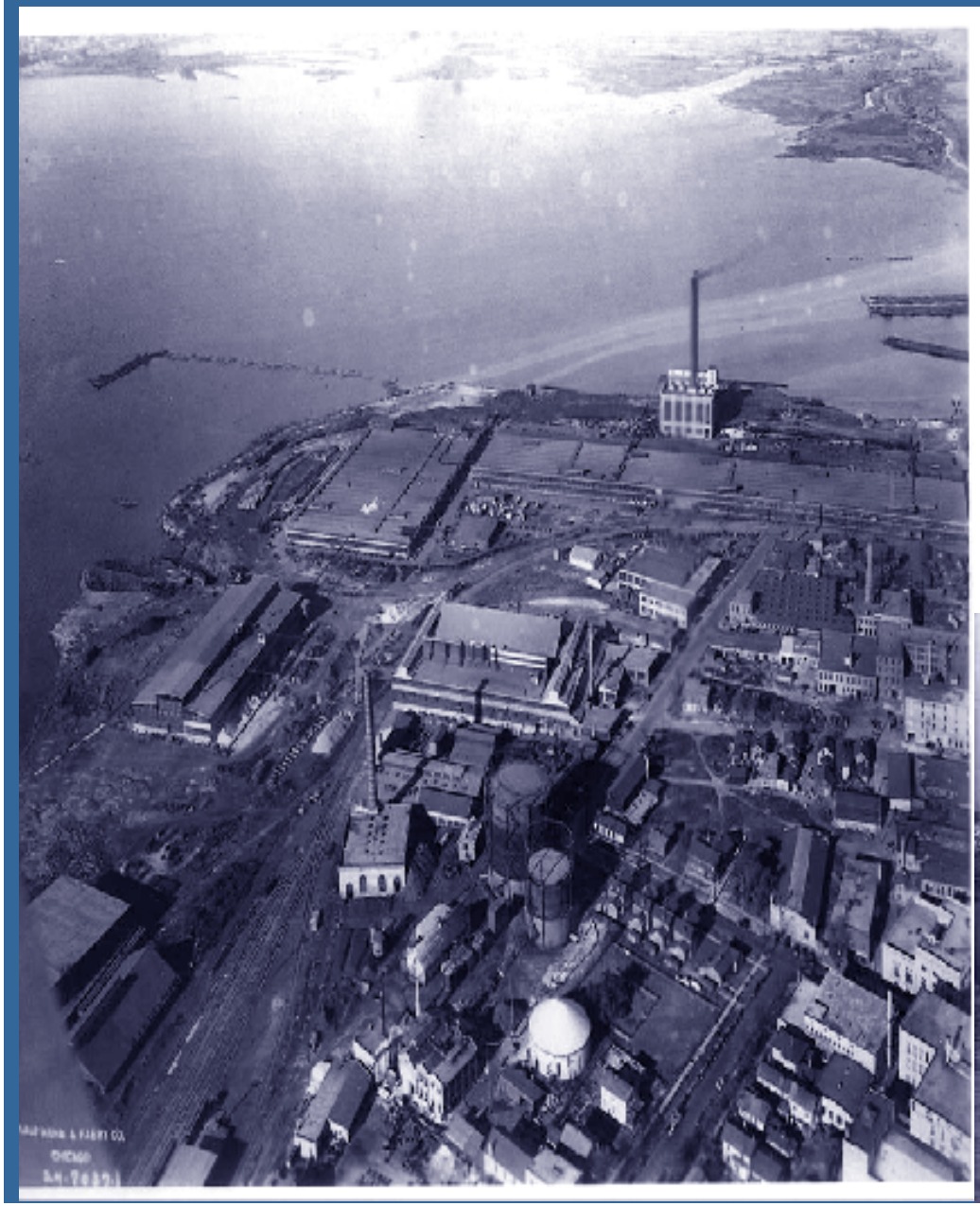


Image: www.michpics.wordpress.com

Image: www.bentley.umich.edu

- Over 16% of open water filled in
- 65% of the shoreline has been hardened

Muskegon Lake, MI: 1900-1960



AWRI Monitoring Program for Muskegon Lake

GOALS:

- Observe short-term and long-term changes in the ecological health of Muskegon Lake
- Use information to help de-list Muskegon Lake as an Area of Concern
- Engage Muskegon community in the process of ownership of the lake

AWRI Monitoring Program for Muskegon Lake

Lake Michigan Center, home of the Annis Water Resources Institute.

AWRI science instructor preparing to deploy an instrument in Muskegon Lake to measure water quality parameters.

AWRI scientist analyzing chemicals from Muskegon Lake in the laboratory.

Muskegon Lake Research Fund Committee Members:

Roger Andersen, Co-Chair
Dr. Bill Schroeder, Co-Chair
Arn Boezaart
Dr. Mike Bozym
Dr. Mike Cerminaro
Roland Crummel
Eric Gielow
Wayne Groesbeck
José Infante
Dr. Bill Jackson
Roger Morgenstern
Gary Noble
Dr. Alan Steinman
Dan Weikel

GRAND VALLEY STATE UNIVERSITY
www.gvsu.edu

community founds
Muskegon County

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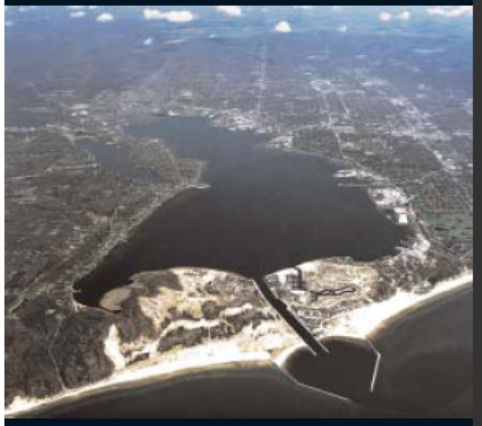

Muskegon Lake Research Fund

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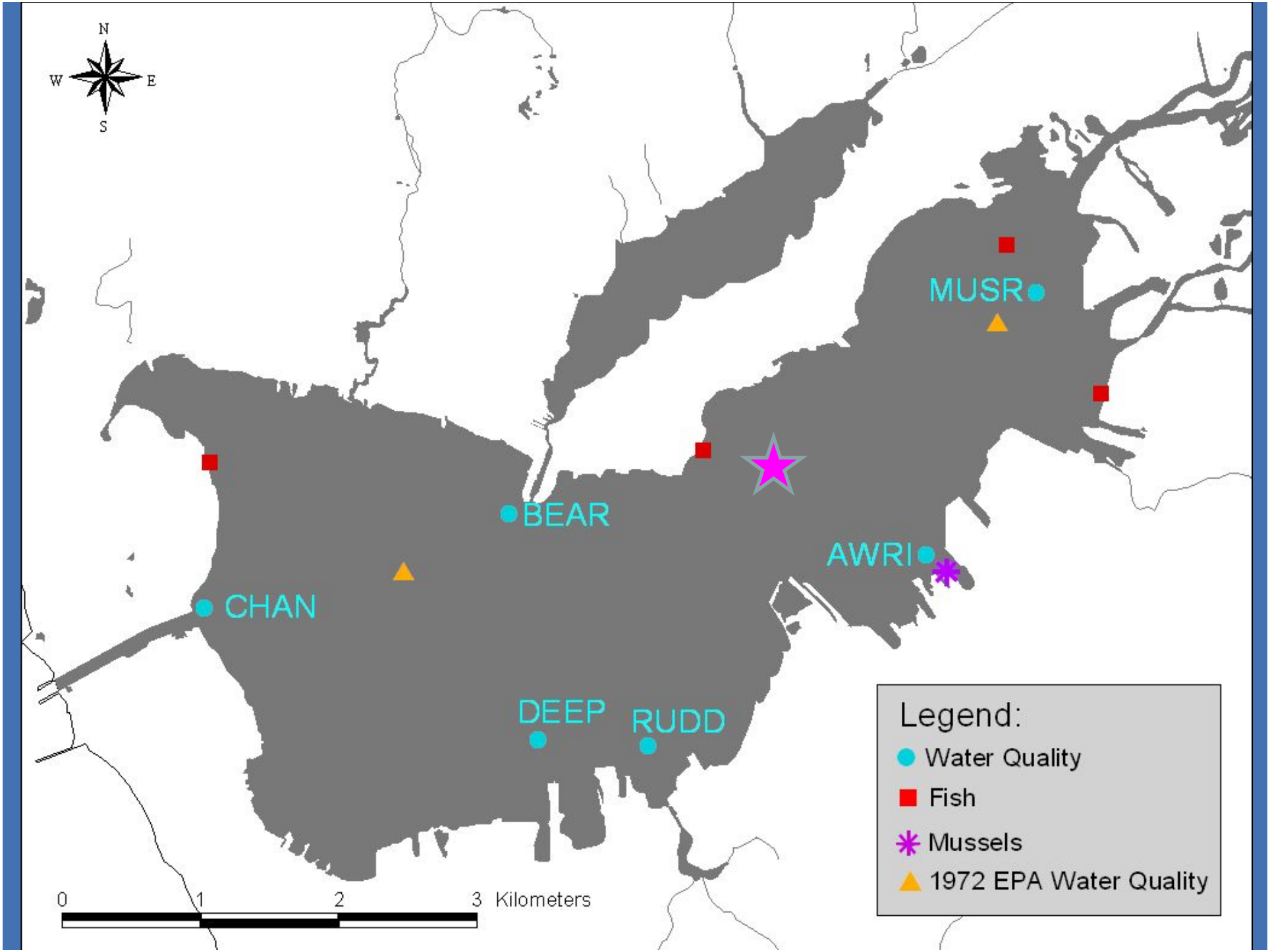
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MUSR
BEAR
AWRI
CHAN
DEEP
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0
1
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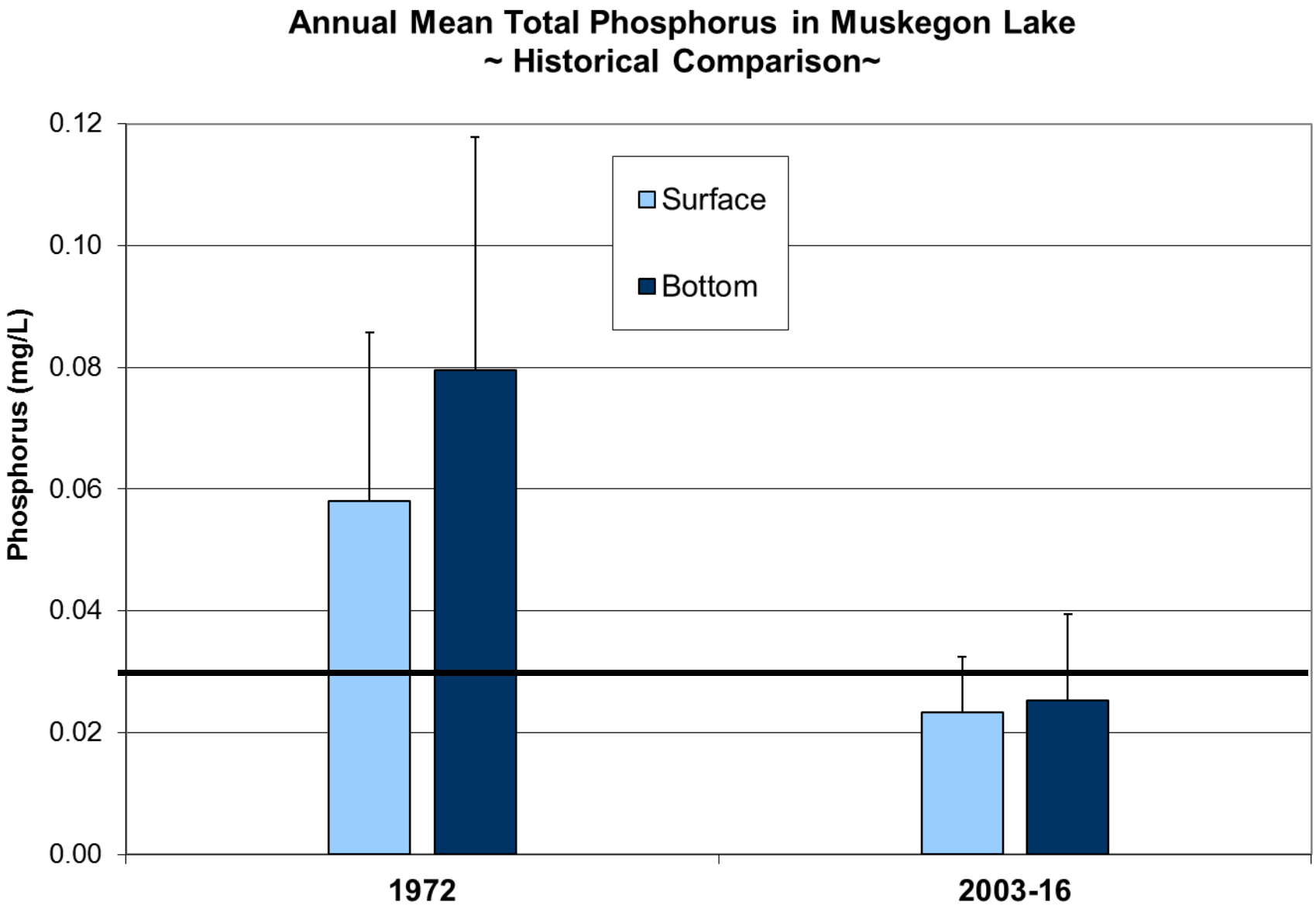
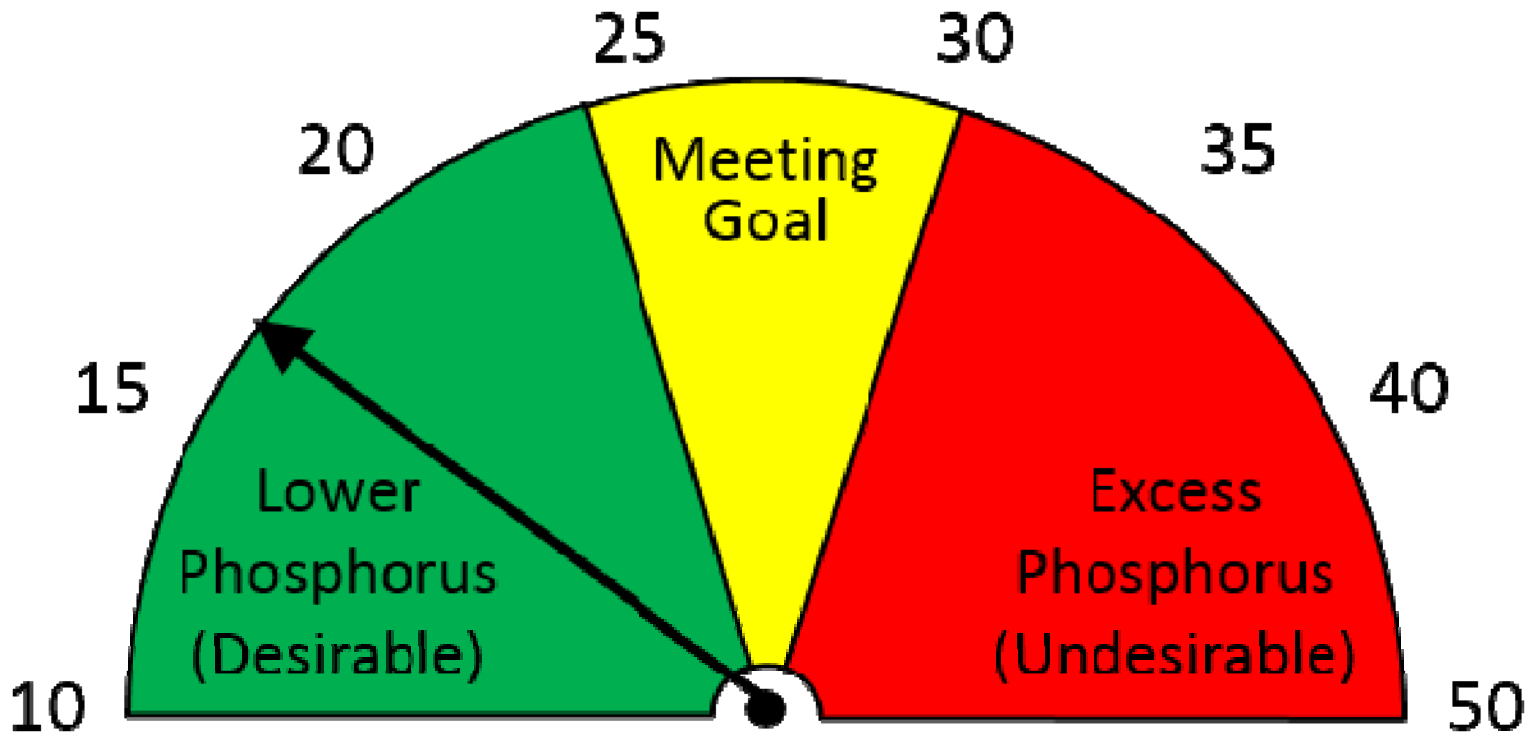
3 Kilometers
Legend:
Water Quality
Fish
Mussels
1972 EPA Water Quality

TOTAL PHOSPHORUS: ‘72 vs. ‘03-‘16



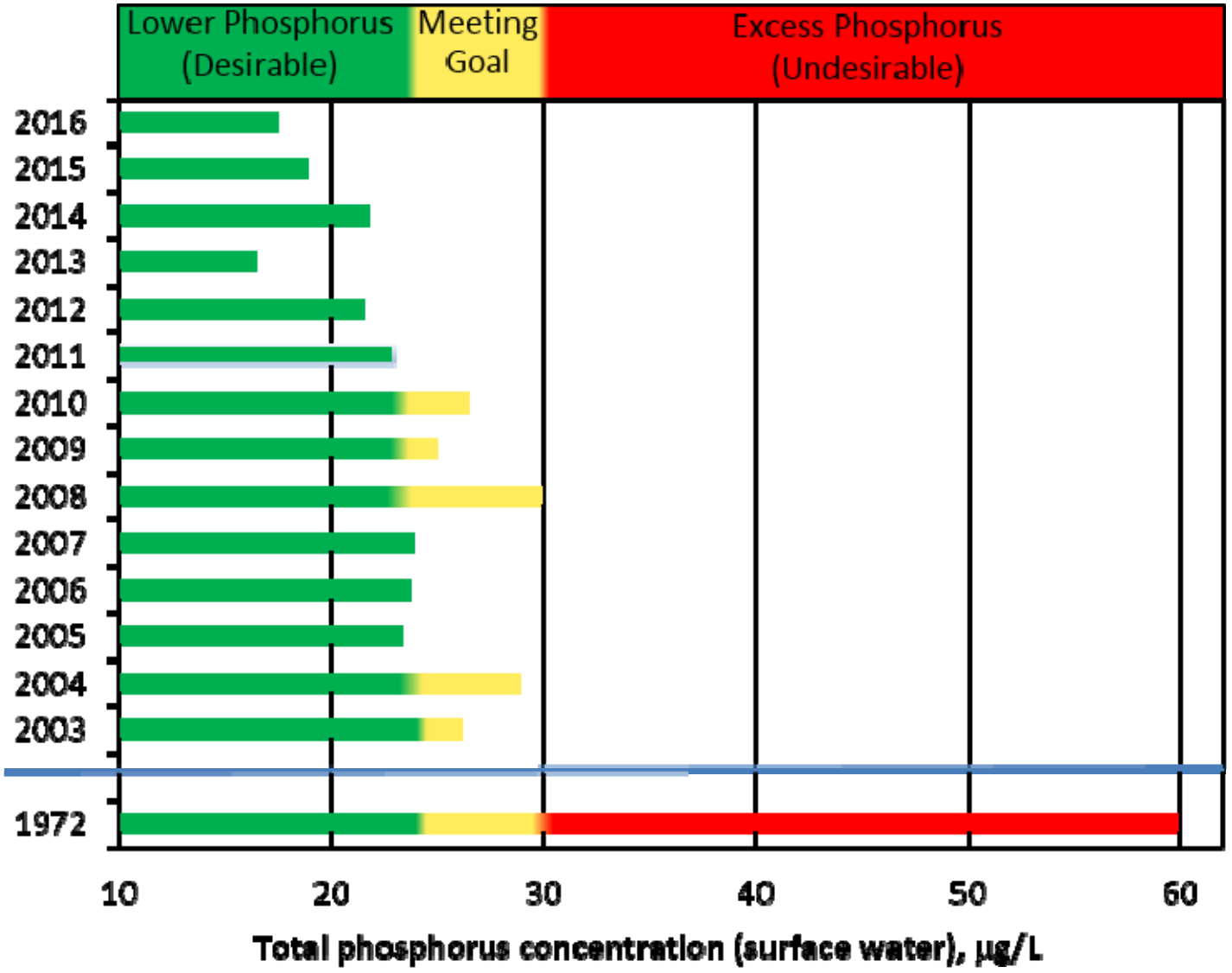
Current Status (2016)



Total Phosphorus Concentration, µg/L

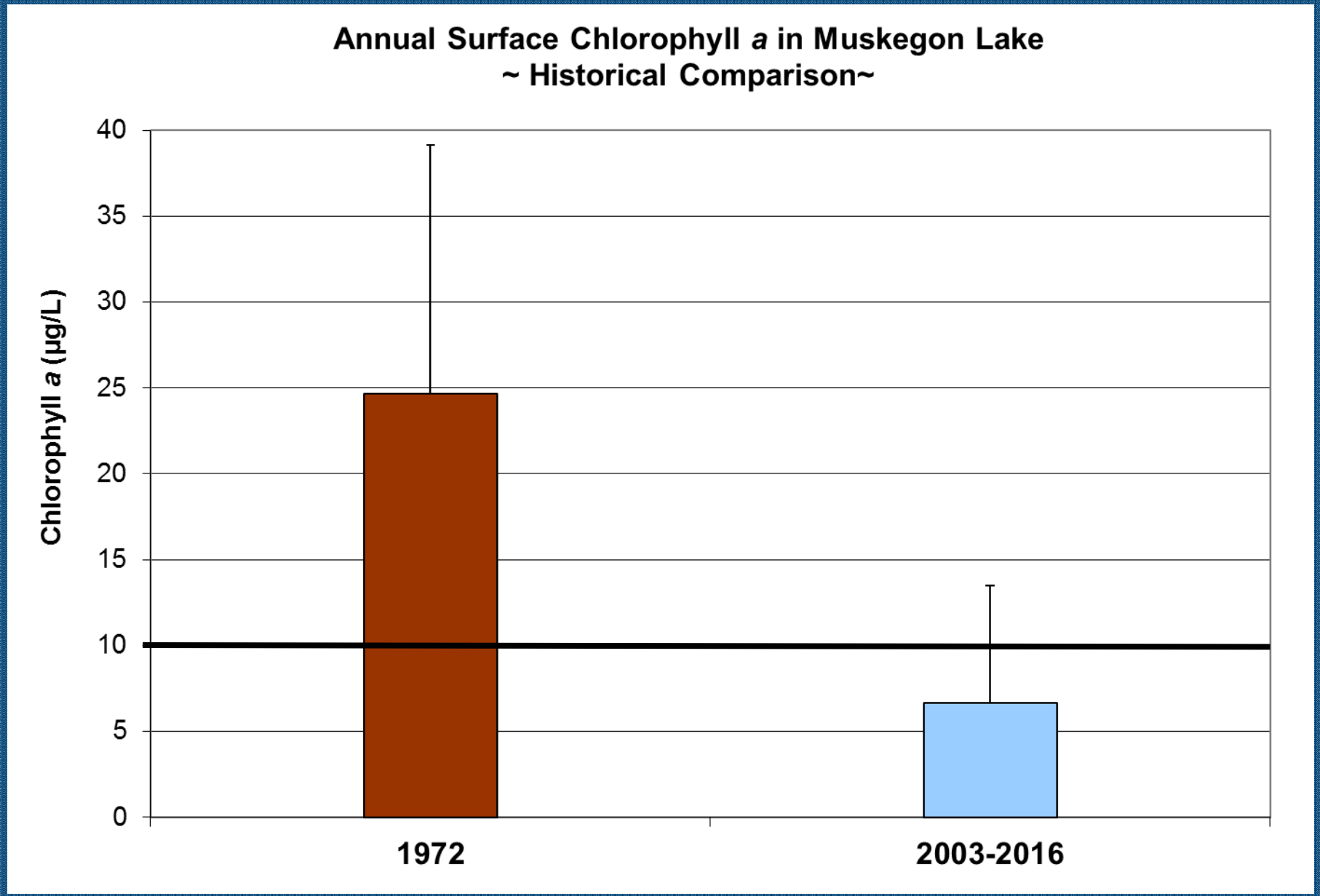
http://www.gvsu.edu/wri/director/muskegon-lake-water-quality-dashboard-78.htm

Current Status (2016)



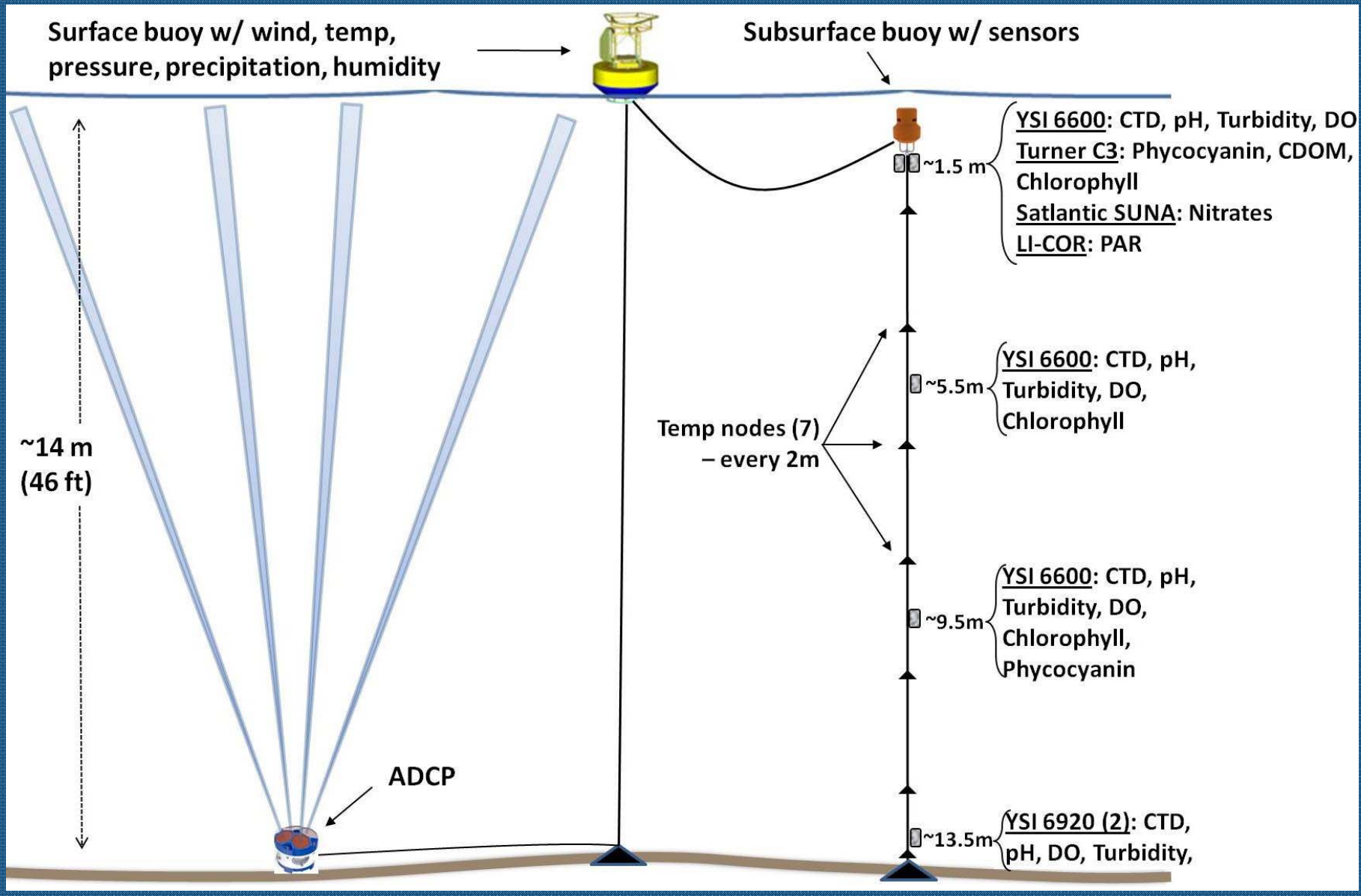
http://www.gvsu.edu/wri/director/muskegon-lake-water-quality-dashboard-78.htm

Chlorophyll *a*: 2003-2016




GVSU Research

Lake Observatory Components



Lake Observatory Website

Grand Valley State University

News & Events | Quick Links | Majors & Programs | People Finder

search

home | site index | contact us

- Buoy Project Description
- New* Current Conditions Data
- New* Interactive Data Plotting Tool
- Older Version - Buoy Current and Historical Data
- Buoy Location
- Buoy Drawings
- Buoy Sensors
- Data Management
- Active Learning Projects for Teachers
- Biddanda Research Web Site

Annis Water Resources Institute

740 W. Shoreline Drive
Muskegon, MI 49444

Google Search

Annis Water Resources Institute

integrating research, education, and outreach to enhance and preserve freshwater resources

print | site index

GVSU's Annis Water Resources Institute was awarded a 3-year grant from the US EPA Great Lakes Restoration Initiative Program to establish a buoy-based observatory in Muskegon Lake. The buoy system will typically be deployed on the lake from April to November, and some sensors may be in the lake year round. Water sensors will measure over 13 parameters including temperature, oxygen, nutrients, light, pH, conductivity, algal pigments, bacterial pigments, and current speed and direction. Air sensors will measure 8 parameters including temperature, wind, humidity, and precipitation. Information is shared through live data display, web and regional observing networks for monitoring, research and educational outreach, and support the restoration of this coastal Great Lakes environment.

Observatory data will provide many hands-on research opportunities for researchers and students to assess the lake ecosystem. Research areas for this intensive data set are extensive and include:

- Monitoring water quality

Muskegon Lake AOC Link

http://www.epa.gov/glnpo/aoc/mskla

News

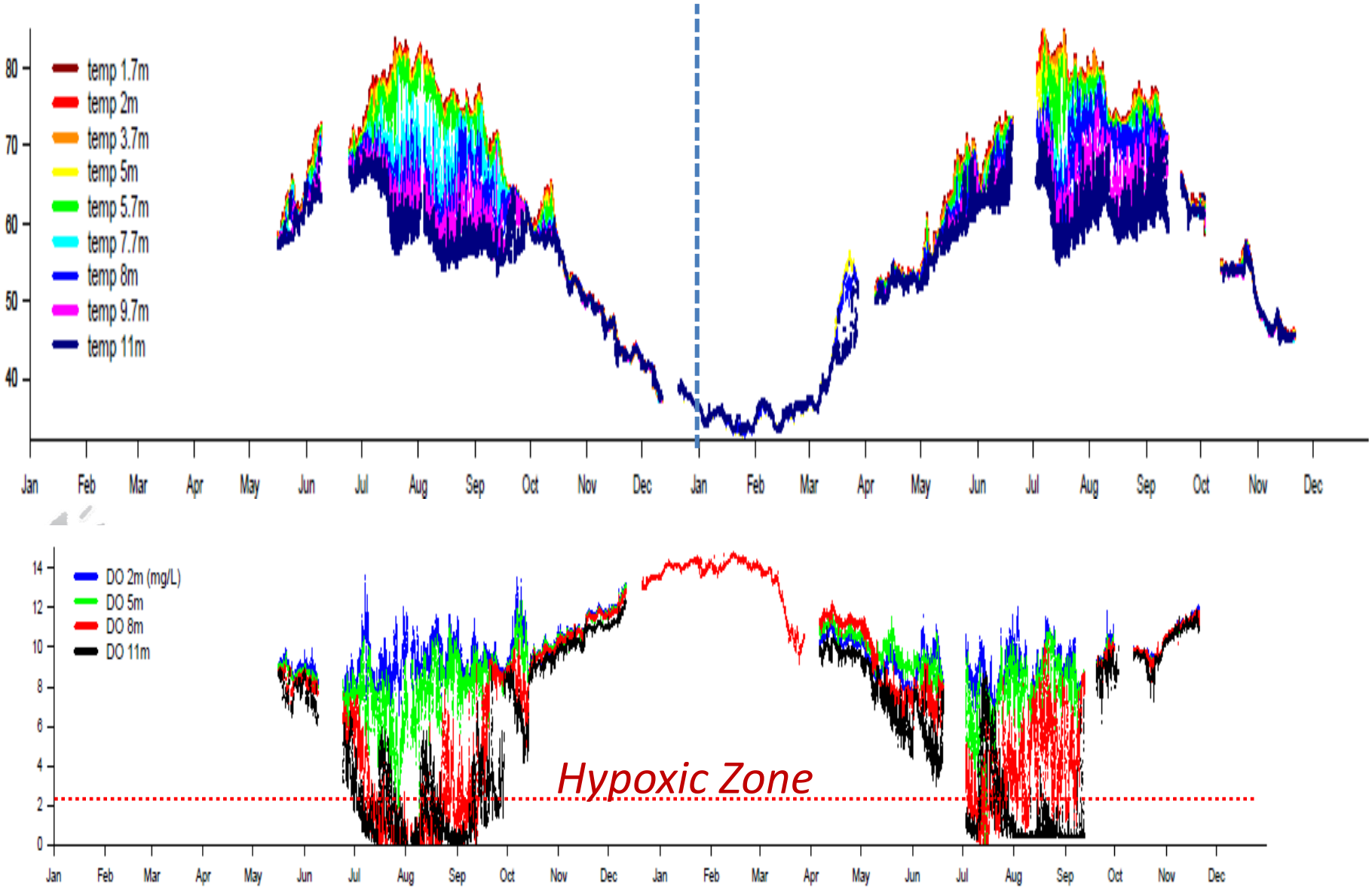
April 9, 2012
2012 Data is now streaming to the internet

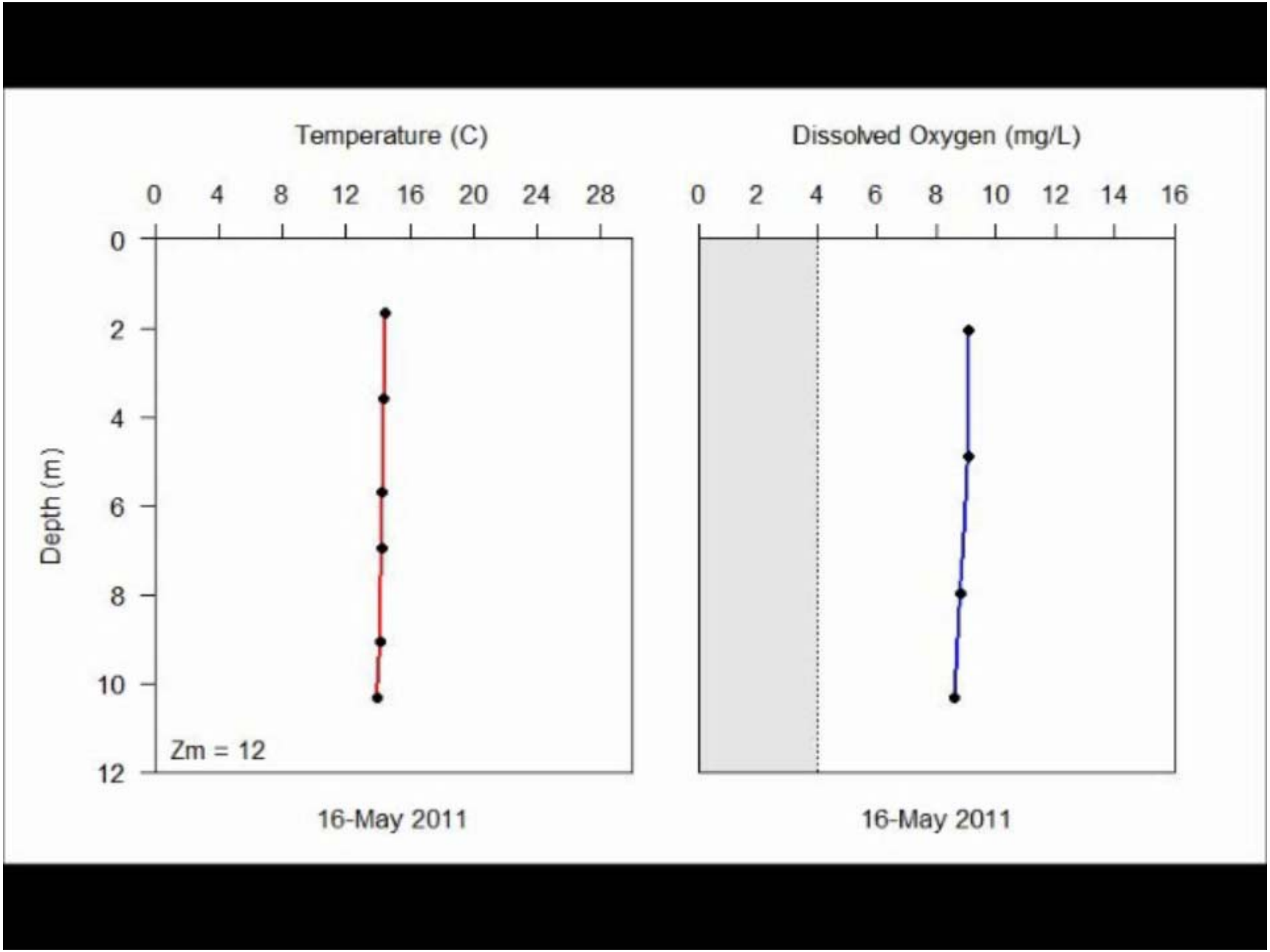
January 9, 2012
Muskegon Lake Buoy has been retrieved for the winter

October 8, 2011
Wet Labs Cycle P Phosphate sensor to be tested in Muskegon Lake

September 14, 2011
Google key words "GVSU Buoy"

Tracking Water Column Temperature & DO in Muskegon Lake 2011 through 2012




Temperature (C)
0 4 8 12 16 20 24 28
0 2 4 6 8 10 12
Depth (m)
Zm = 12
16-May 2011
Dissolved Oxygen (mg/L)
0 2 4 6 8 10 12 14 16
16-May 2011

- Implanting ultrasonic emitters
- Hydrophone and passive receivers detect unique frequencies

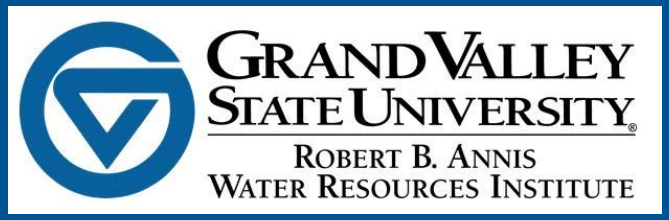
Before Turnover

2008-2009

After Turnover

2008-2009

Muskegon Lake Area of Concern Habitat Restoration Project Partners



- $10 million project: American Recovery and Reinvestment Act (NOAA)

- Restoration Targets:
  - Soften 10,007 feet of Hardened Shoreline
  - Restore ~27 acres of Wetland Habitat
  - Remove or improve 23.6 acres of Unnatural Lake Fill (135,000 yd^3)

Before

After

Images: Kathy Evans

Return on Investment

- Created 80 jobs
- Retained 45 jobs
- Equal to 35,933 labor hours
- Economic impact: 6.6 ROI ($10 million investment resulted in $66 million)
- Enhanced civic pride

WATCH MUSKEGON

Summary: Muskegon Lake

- Long-term monitoring has allowed us to rigorously quantify changes in Muskegon Lake ecology and identify research needs (low DO zones; 3-D hydrodynamic model)

- This science has engaged the public through their philanthropy, resulting in greater awareness and sense of ownership; leverage additional funds


N
Bear
Lake
Muskegon
Lake
AWRI
Lake
Michigan
Michigan
Muskegon
County

Bear Lake

Objectives

Primary: Restore additional habitat in the Muskegon Lake AOC

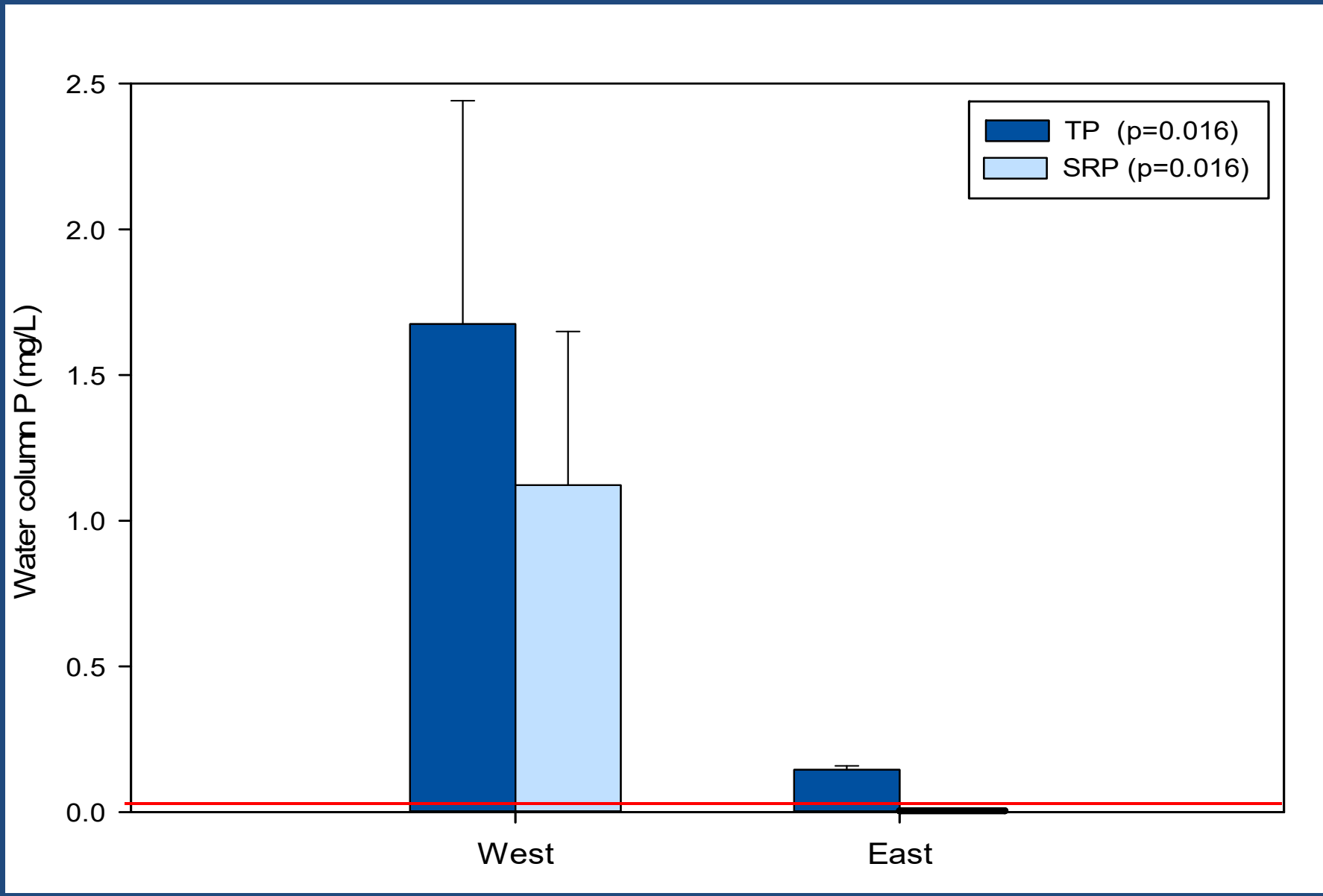
Secondary: Don’t contribute to excess phosphorus to downstream Bear Lake

Hydrography and TP Concentrations

Project Elements

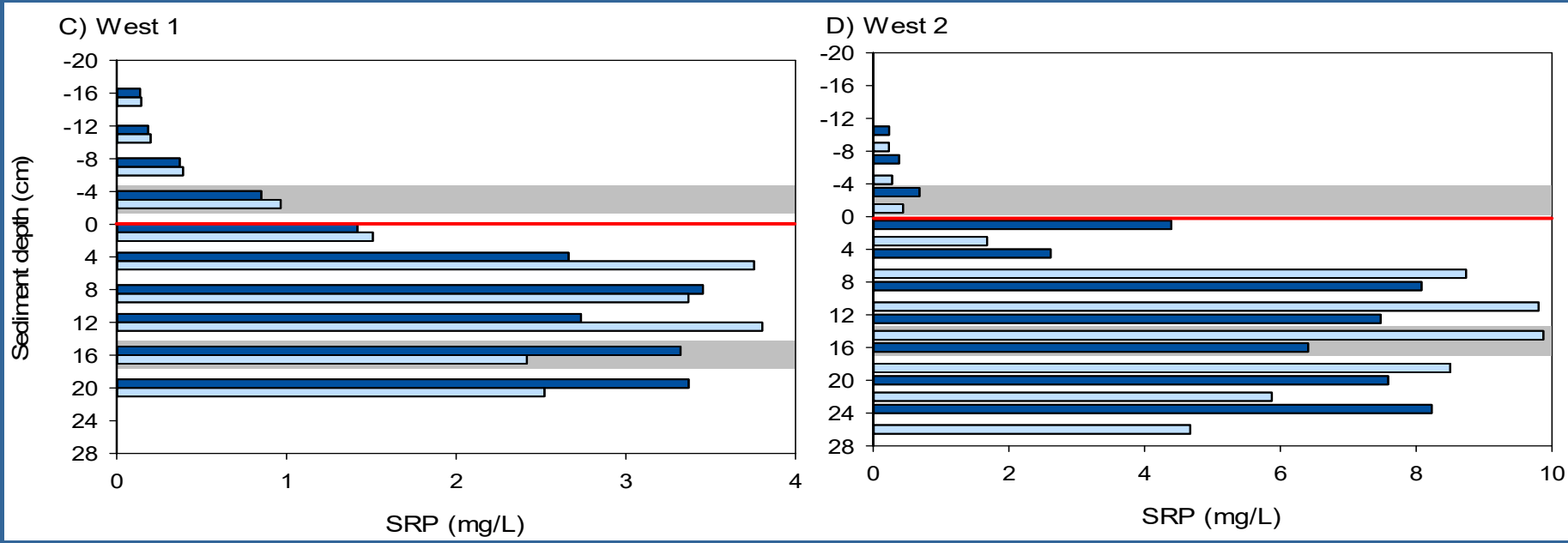
- Examine P biogeochemistry in water column and sediments
  - sediment characterization
  - P isotherms
  - porewater samplers
  - P fractionation
- Conduct simulated hydrologic connection experiments

Water Column TP and SRP Concentrations



Sediment Phosphorus: Porewater

Muck Fields Sediment Porewater SRP



Steinman & Ogdahl (2016) *Env. Sci. Poll. Res.*

Peeper SRP Concentrations (mean ± SD)

Depth	West Field (undredged)	East Field (dredged)
Surface Water (-3 to 0 cm) (µg/L)	735 ± 228	9 ± 6
Sediment (14 to 17 cm) (µg/L)	5,506 ± 3,307	222 ± 198

P Release Experiment

- Simulate reconnection of Bear Creek water to muck field sediments

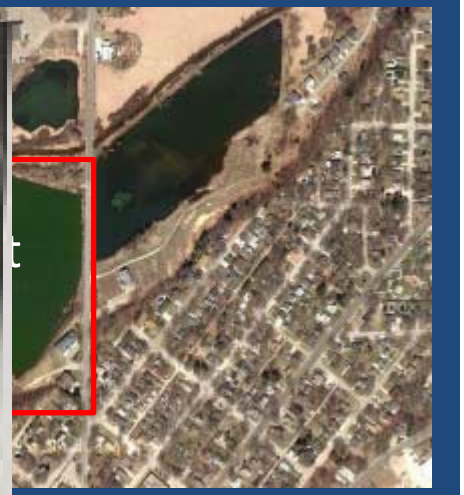
Smit & Steinman (2015) *Wetlands*

Experimental Design

Sediment Source	Water Source	
	Bear Creek* (reconnect)	East/West Pond* (control)
East Field	6 X	6X
West Field	6X	6X

*Repeated at ambient temperature and at +2°C in July/October

De

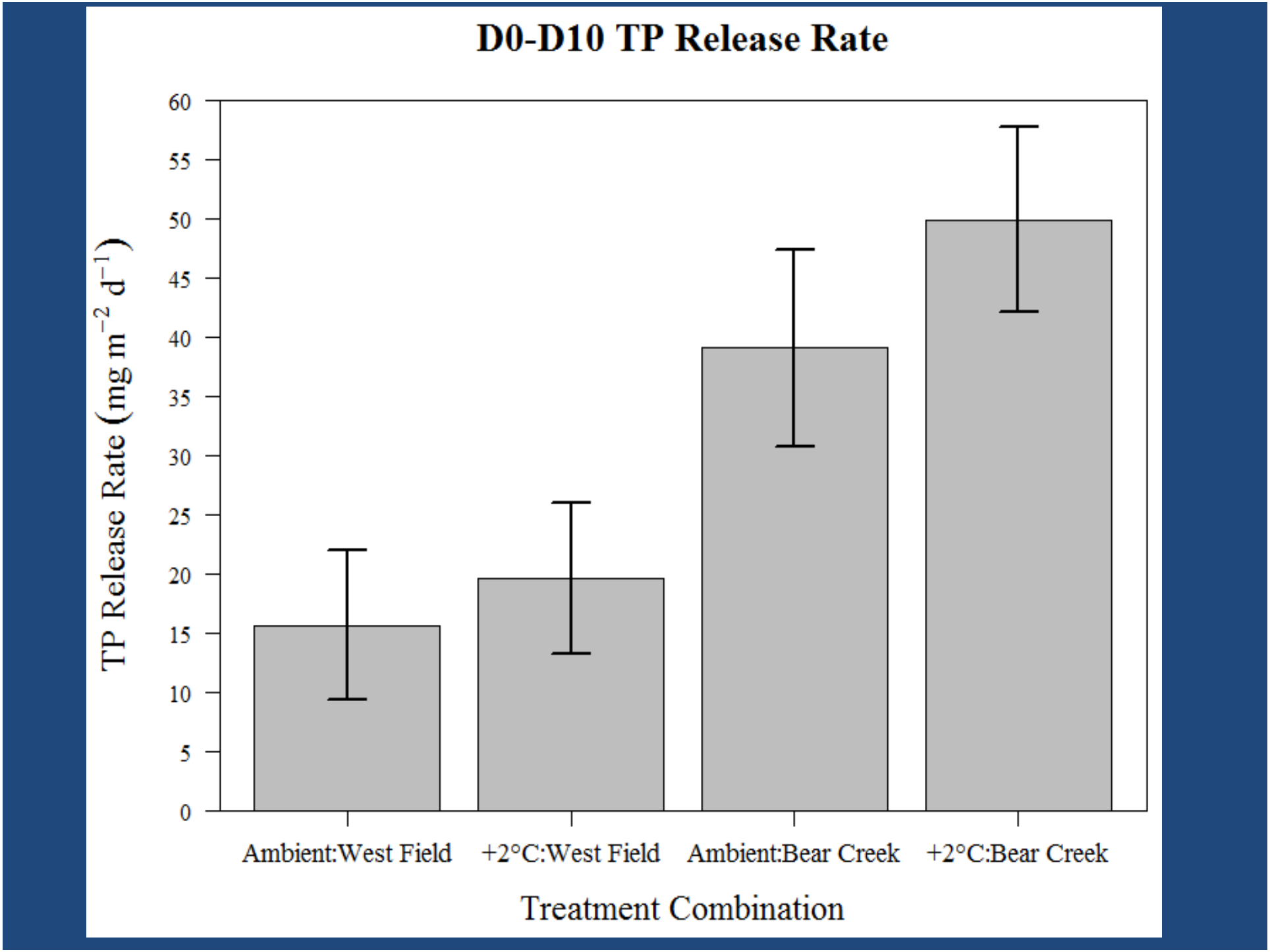


Ambient

West Field

West Field

6x


D0-D10 TP Release Rate
TP Release Rate (mg m^{-2} d^{-1})
0
5
10
15
20
25
30
35
40
45
50
55
60
Ambient:West Field
+2°C:West Field
Ambient:Bear Creek
+2°C:Bear Creek
Treatment Combination

July 2015

June 2016

SITE	2014: PRE	2016: PRE	12/12/16: POST	4/12/17: POST
SRP (µg/L)				
East Pond	3	6	47	5
West Pond	498	341	22	5

Summary: Bear Lake Wetland

- Need to address prior land use as part of habitat restoration
- Modest investments in research help inform restoration design
- Reducing P loads should reduce Bear Lake eutrophication issues, including HABs

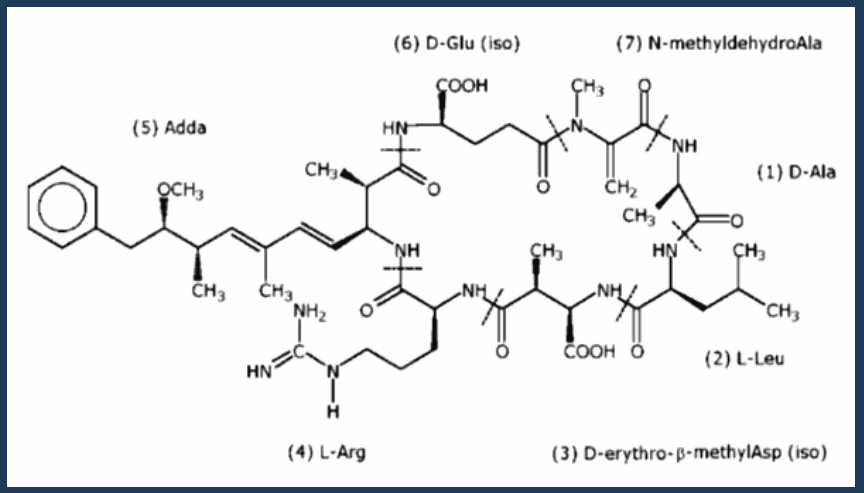
Harmful Algal Blooms (HABs)

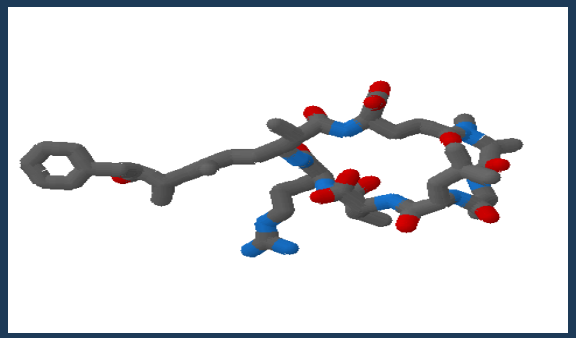
Microcystin is the most common cyanotoxin produced by HABs → hepatoxin and tumor promotor.

WHO standards:

- drinking water: 1 µg/L
- recreational: 20 µg/L

Microcystins





- Polypeptide
- ~100 congeners (LR, RR, YR, etc.), 200 related compounds
- Produced by *Microcystis* and other genera
- LD_{50} 25-60 µg/kg (cyanide 4 mg/kg)
- Hepatotoxin and tumor promoter

Muskegon/Bear Lakes

Parameter	Muskegon	Bear
Surface Area (km^2)	16.8	1.66
Mean Depth (m)	7.1	2.1
Max. Depth (m)	23	3.1
HRT (d)	21	30
Mean TP (µg/L)	~25	~45
Mean Chl *a* (µg/L)	~7	~24
Trophic status	Meso/Eutrophic	Eutrophic

Methods

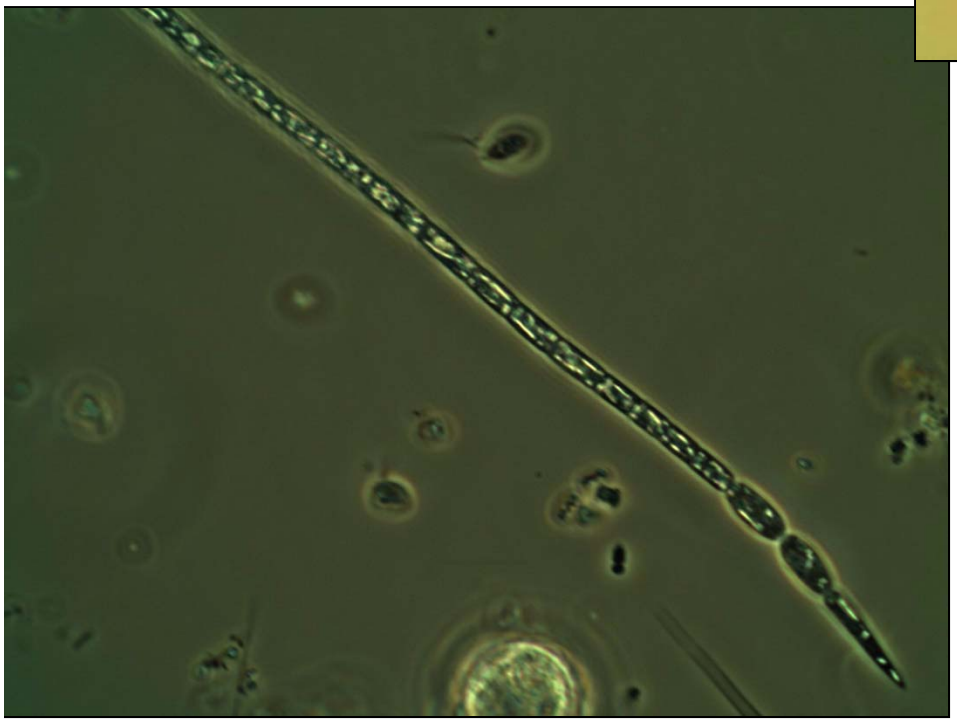
Field

- - Integrated 1 m water sample
- - 3 pelagic and 3 beach samples
- - 2X in July and August, 2010

Laboratory

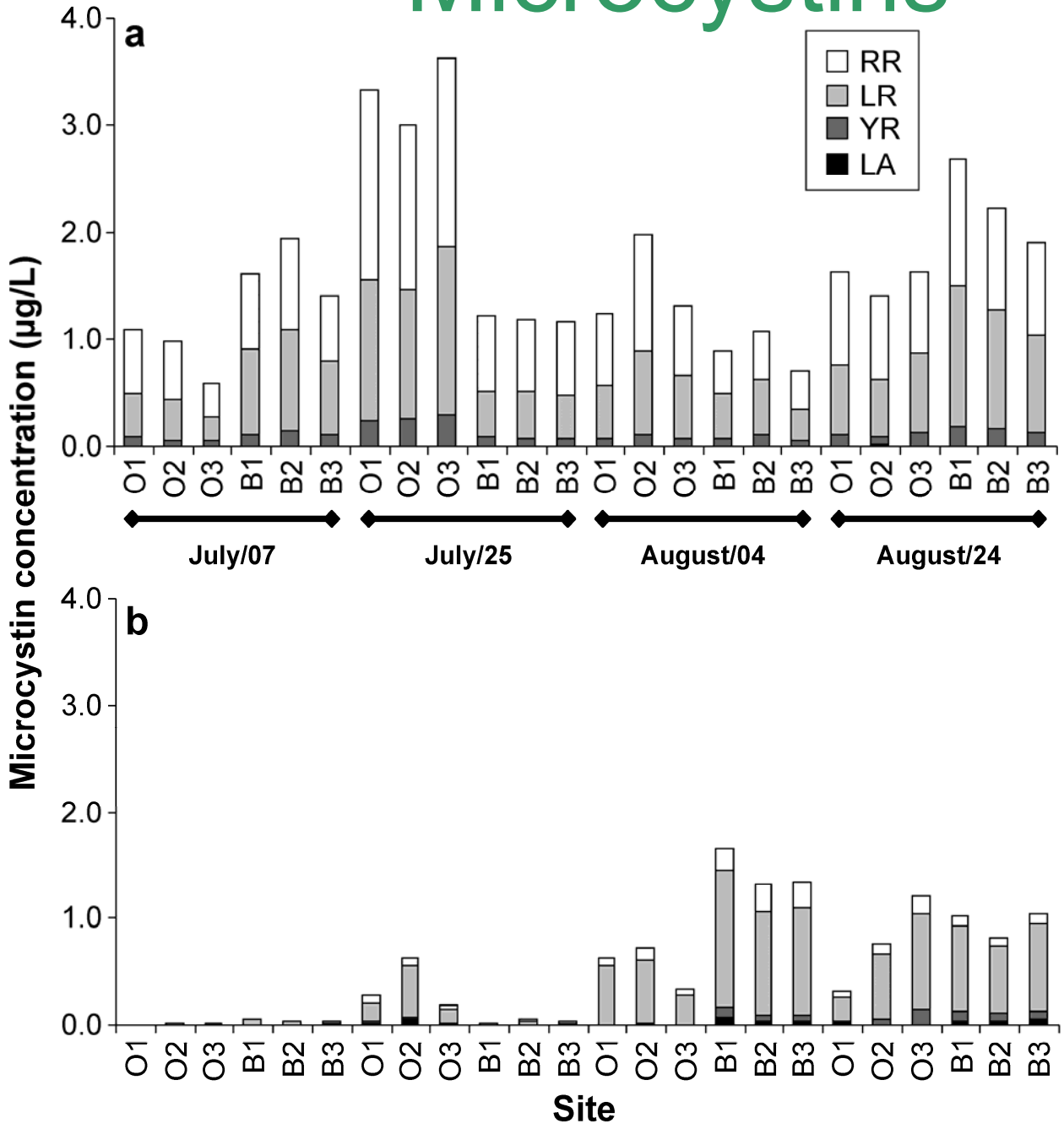
- HPLC/MS Microcystins LR, RR, LA, YR and cylindrospermopsin
- PCR analysis of the PKS gene
- Nutrients and limnological parameters
- Community structure

Cylindrospermopsis



Hong et al. (2006) J. Great Lakes Research
Gillett and Steinman (2011) J. Great Lakes Research

Microcystins

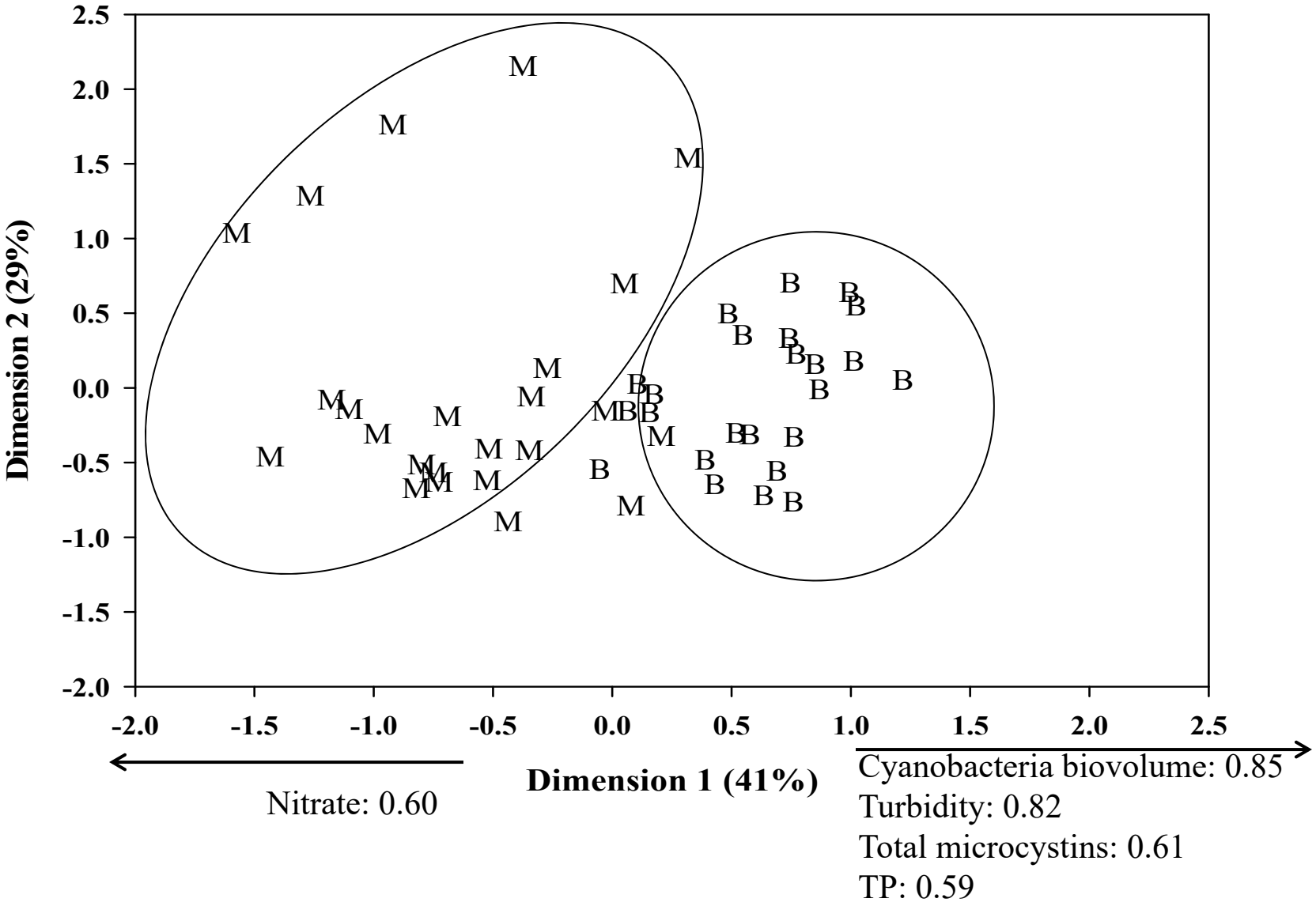


Bear Lake

Musk. Lake

Xie et al. 2011

Non-metric multidimensional scaling ordination



Cyanotoxin Correlations

- Bear Lake: Microcystins were positively correlated with TP ($p<0.001$) and negatively correlated with ammonia and nitrate ($p<0.01$)
- Muskegon Lake: Microcystins were negatively correlated with nitrate ($p<0.01$)
- Negative correlations with ammonia and nitrate have been observed by others (Blomqvist et al., 1994; Amé and Wunderlin, 2005)

Cylindrospermopsis raciborskii

- *C. raciborskii* was positively correlated with turbidity and chlorophyll *a* in both lakes ($p<0.001$)
- The strain was not capable of producing cylindrospermopsin due to inactivity/ absence of PKS gene
- Bear Lake appears to be the source of *C. raciborskii* in Muskegon Lake

HAB Conclusions

- Despite their hydrologic connectivity, algal dynamics differed among lakes
- Local environmental conditions appear to have stronger influence than regional effects
- Drowned mouth lakes susceptible to *C. raciborskii* invasion (elevated nutrients and turbidity) but our strain not capable of cylindrospermopsin production

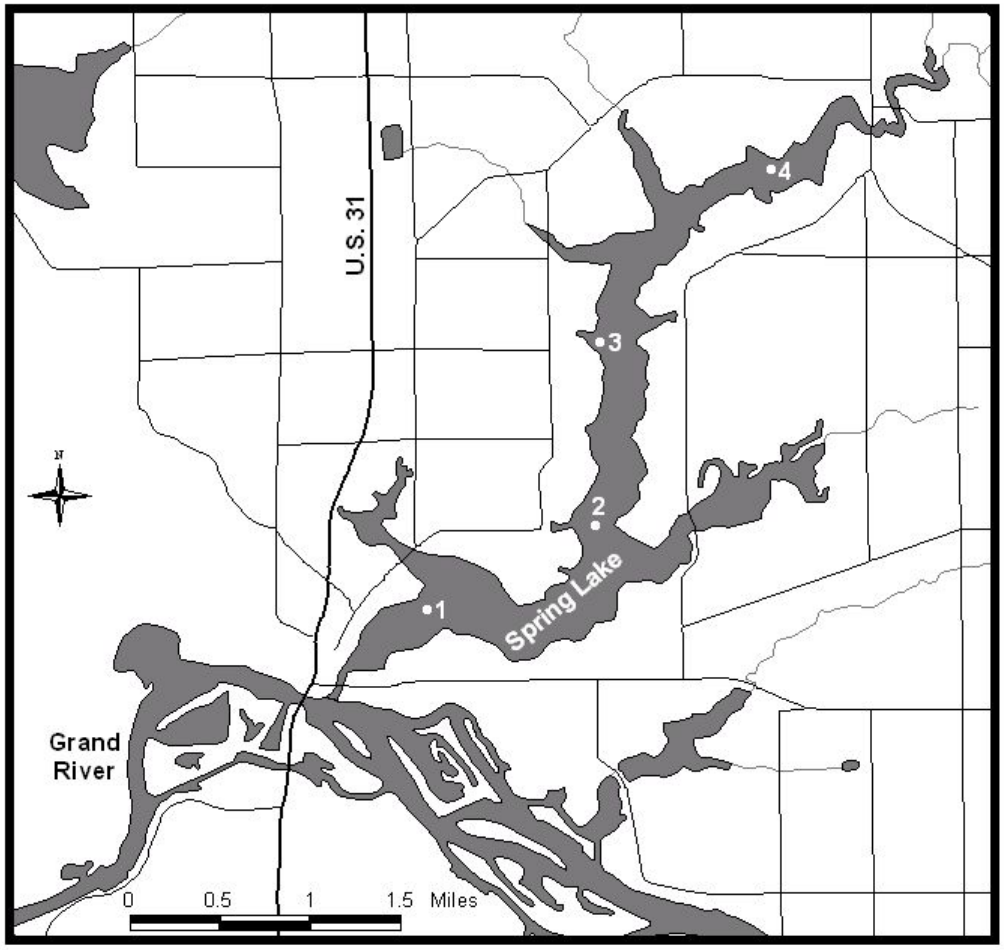
Development of Rapid Assessment Methods for Harmful Algal Blooms using qPCR and Image Flow Cytometry

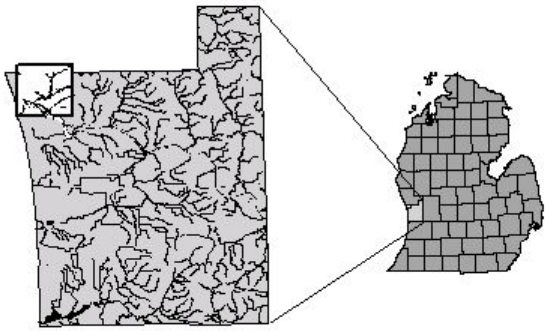
- qPCR-based assays that quantify *Microcystis* abundance, relative ratio of toxic to non-toxic strains, and measure microcystin gene expression → information regarding toxin production activity.

- Image Flow Cytometry (IFCM) method based on RING-FISH (Recognition of Individual Genes by Fluorescence In-Situ Hybridization) → qualitative and quantitative measurements of microcystin production.

These complementary methods establish a near real-time screening tool (IFCM) followed by confirmatory methods (qPCR) enabling managers to make more informed decisions

Restoring Spring Lake, MI





Legend

- Sampling Site
- State/County Road
- U.S. Highway
- Lake, pond, or river
- Stream

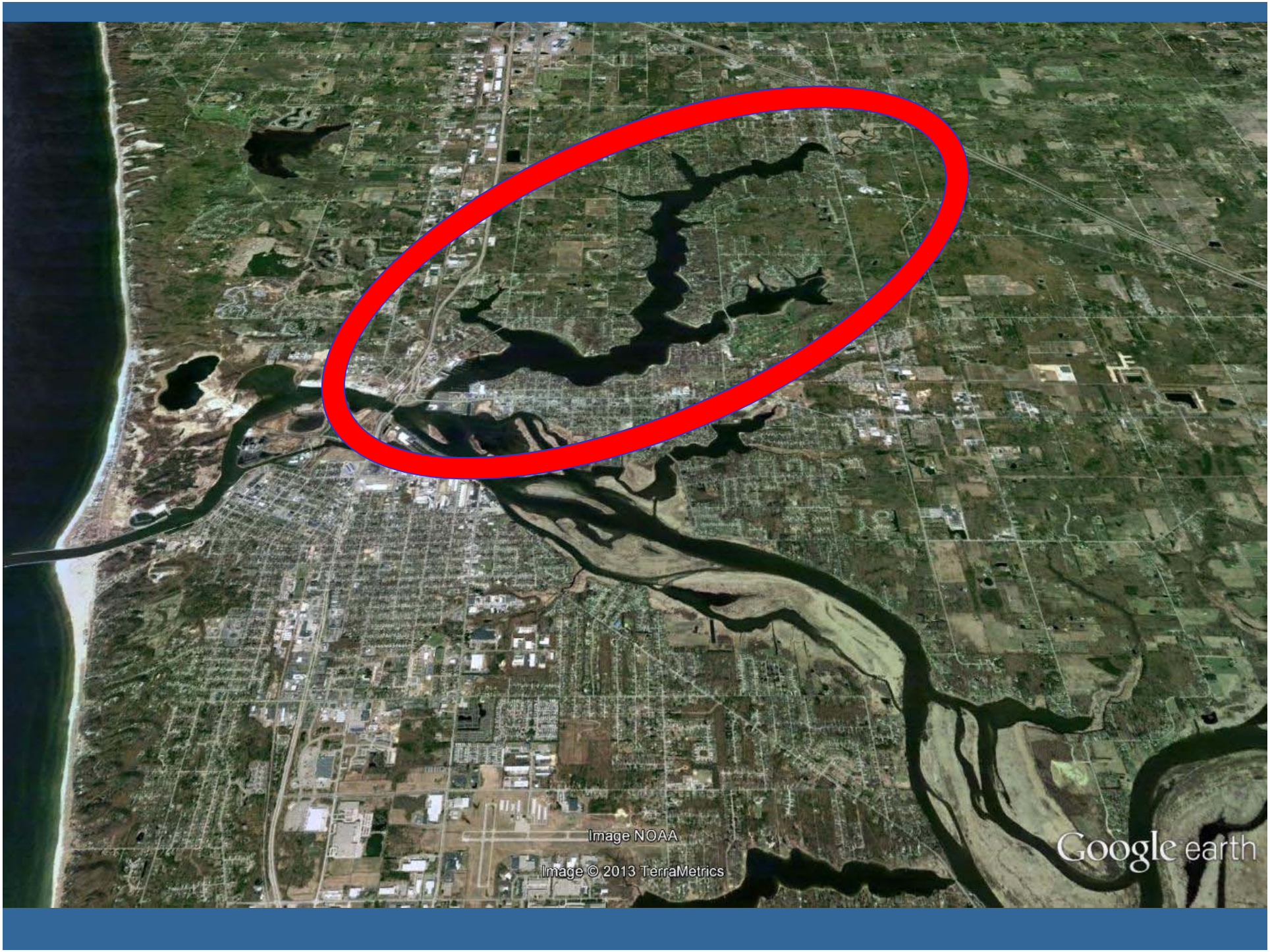


Image NOAA
Image © 2013 TerraMetrics
Google earth

1978 Land Use and Cover

Legend

Land Use and Cover Description	Total Acres	%
Bare/sparsely vegetated	237	0.7
Commercial/industrial/transportation	838	2.5
Coniferous forest	3,267	9.7
Cropland and pasture	7,176	21.2
Deciduous forest	11,887	35.1
Emergent herbaceous wetlands	127	0.4
Herbaceous open land/grasslands	479	1.4
Mixed forest	0	0.0
Orchards/vineyards/other	598	1.8
Other agricultural land	13	0.0
Residential	4,221	12.5
Shrub/low-density trees	3,414	10.1
Urban/recreational grasses	286	0.8
Water	1,144	3.4
Woody wetlands	131	0.4

Data Sources:
1978 Land Use and Cover - Michigan Resources Information System (MIRIS): Michigan Department of Natural Resources, Land and Water Management Division

Base Information - Michigan Center for Geographic Information, Department of Information Technology, 2008

0 0.5 1 2 3 4 Miles

0 0.5 1 2 3 4 Kilometers

Information Services Center
Annis Water Resources Institute
Grand Valley State University

Map Prepared: March 2009

2006 Land Use and Cover

Legend

Land Use and Cover Description	Total Acres	%
Bare/sparsely vegetated	184	0.5
Commercial/industrial/transportation	1,504	4.4
Coniferous forest	2,643	7.8
Cropland and pasture	4,140	12.2
Deciduous forest	11,186	33.1
Emergent herbaceous wetlands	247	0.7
Herbaceous open land/grasslands	755	2.2
Mixed forest	5	0.0
Orchards/vineyards/other	834	2.5
Other agricultural land	214	0.6
Residential	9,343	27.6
Shrub/low-density trees	963	2.8
Urban/recreational grasses	523	1.5
Water	1,187	3.5
Woody wetlands	92	0.3

Data Sources:
2006 Land Use and Cover - AWRI-GVSU Updated using 2006 National Agricultural Imagery Program (NAIP) Digital Orthophotograph with AWRI-GVSU 1992-97 Land Use and Cover Data

Base Information - Michigan Center for Geographic Information, Department of Information Technology, 2008

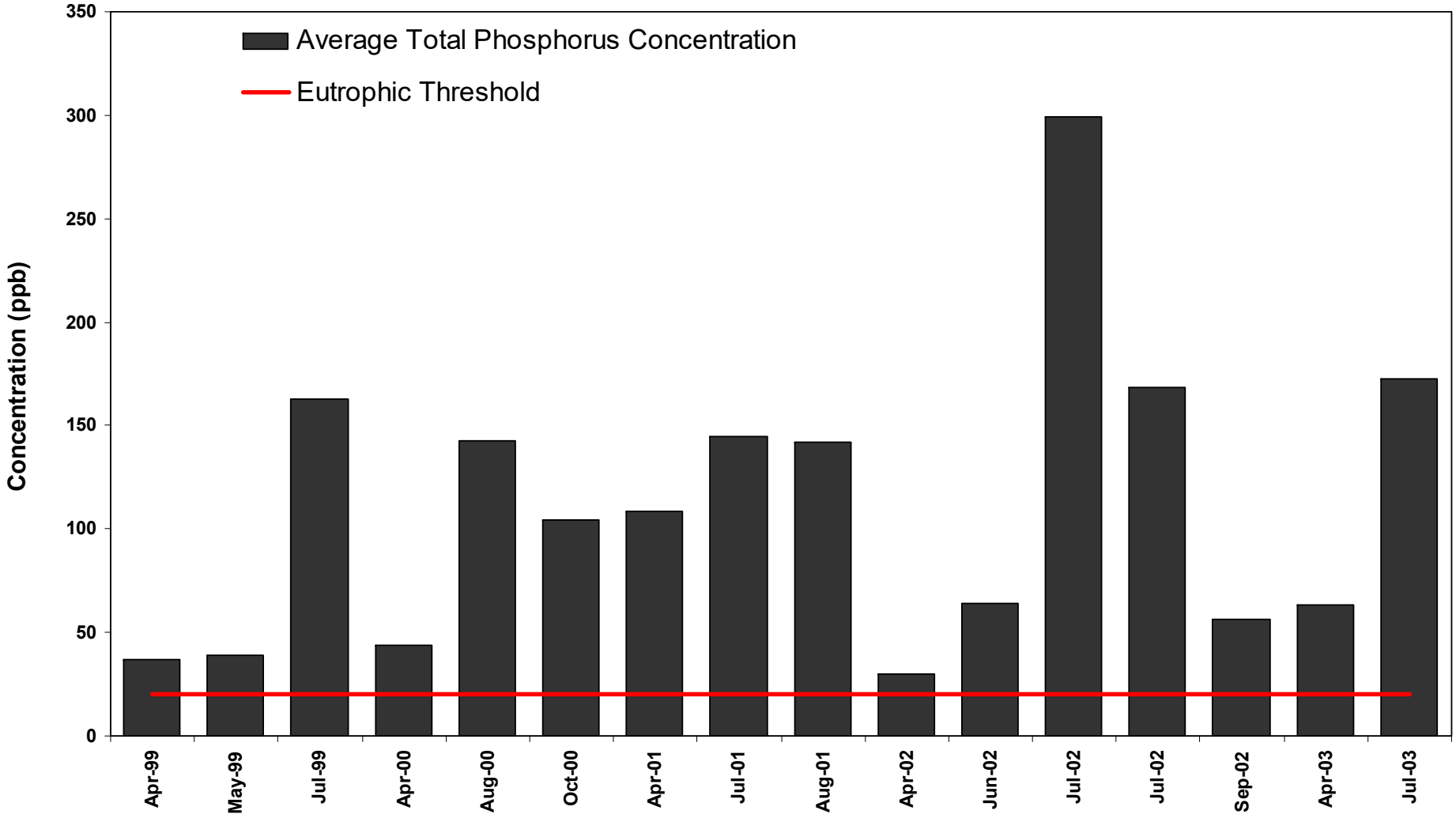
0 0.5 1 2 3 4 Miles

0 0.5 1 2 3 4 Kilometers

Information Services Center
Annis Water Resources Institute
Grand Valley State University

Map Prepared: March 2009

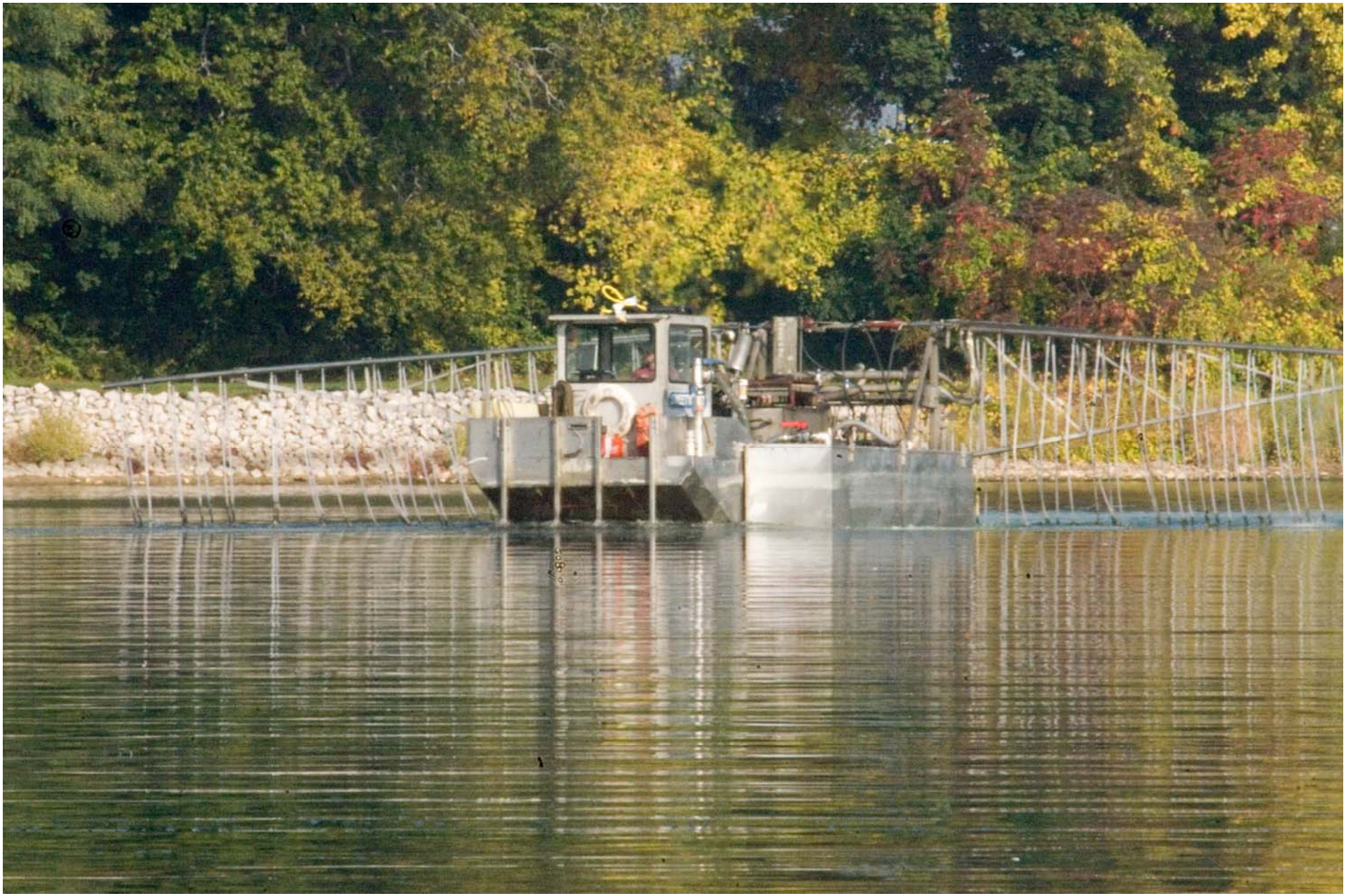
Total Phosphorus: Spring Lake



Alum Application

- Application date: Oct—Nov, 2005
- Total application: 1,163,00 gallons
- Surface application using spray nozzles
- Treatment area: ~2.4 km^2 (~46%)
- Treatment dose: ~80 g Al/m^2

Treatment Barge



Maximum TP Flux Rates (mg P/m^2/d)

2003 (pre-alum)	2006 (post-alum)	2010 (5 yr post-alum)	2016 (11 yr post-alum)
17.97 ± 7.00	0.79 ± 0.43	2.27 ± 0.40	1.25 ± 0.55

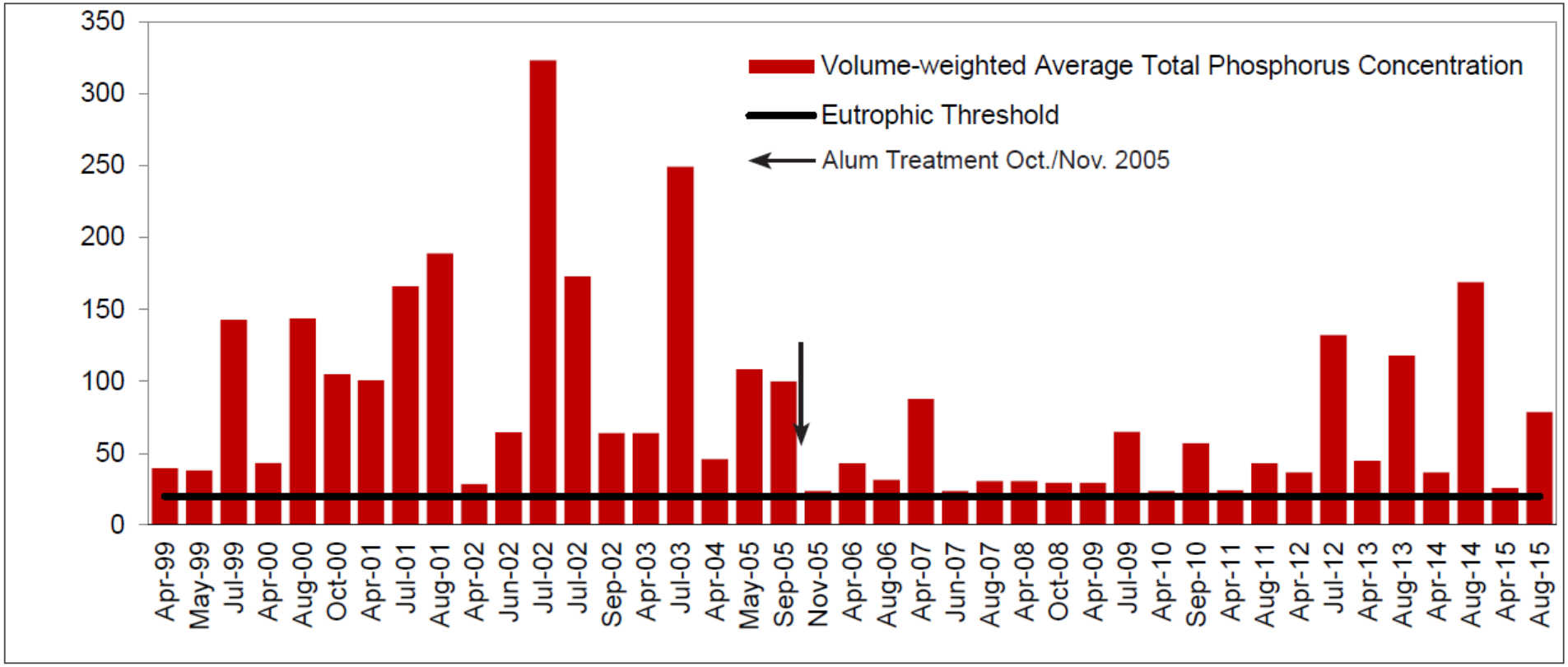
Steinman and Ogdahl (2004, 2010, 2012)

Maximum TP Concentrations (µg/L)
(hypoxic sediment incubations)

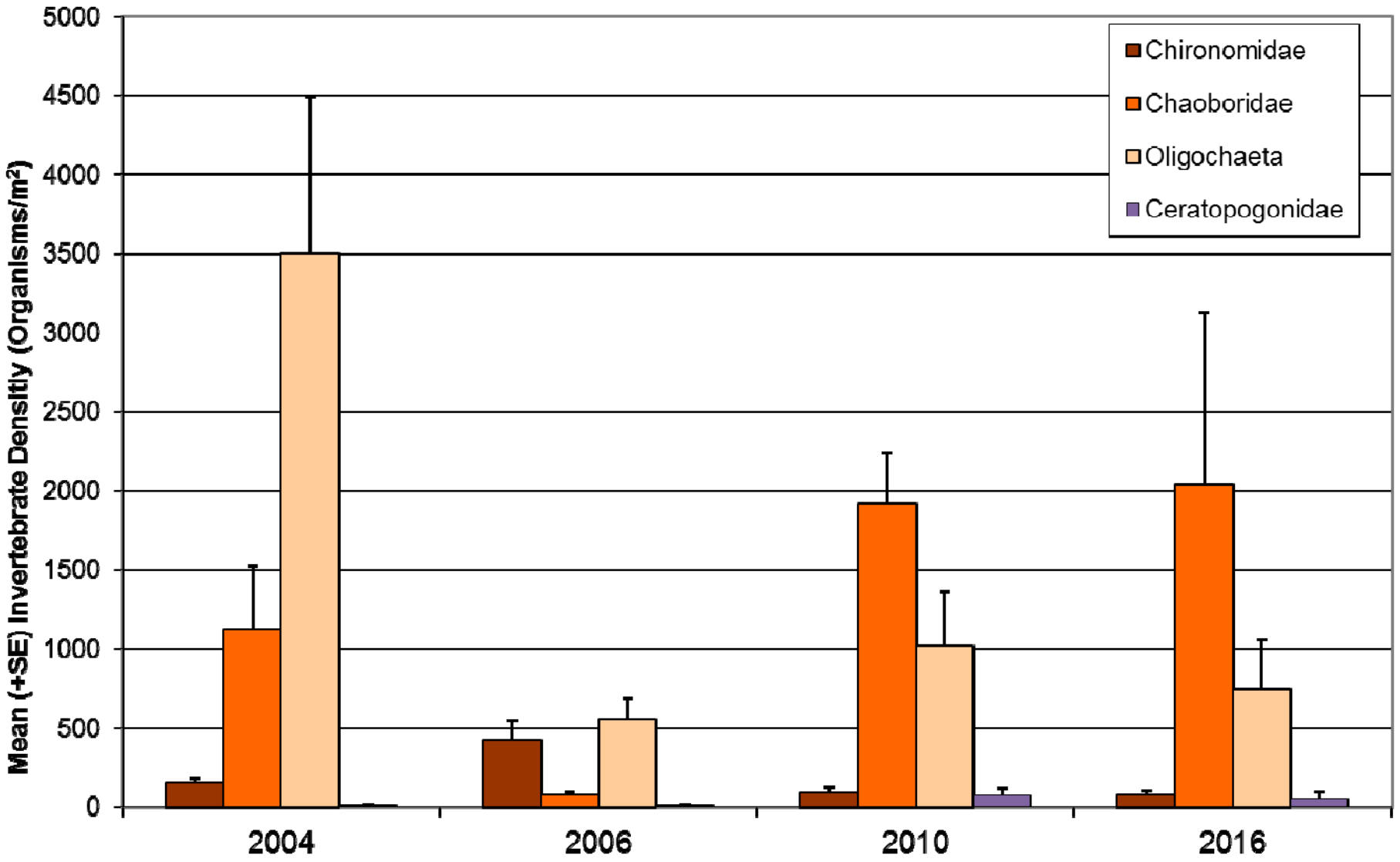
2003 (pre-alum)	2006 (post-alum)	2010 (5 yr post-alum)	2016 (11 yr post-alum)
913 ± 305	55 ± 35	203 ± 56	290 ± 157

Steinman and Ogdahl (2004, 2010, 2012)

Total Phosphorus Concentration (µg/L)



Spring Lake Invertebrate Densities



Spring Lake Summary

- Alum application effective in short-term
- Alum treatment is not a panacea—treats the symptom, not the disease
- Ultimately, must control external loading
- Experiments this summer to determine limiting nutrient

Acknowledgements

Funders: NOAA, US EPA, NASA, Community Foundation for Muskegon County, Spring Lake-Lake Board

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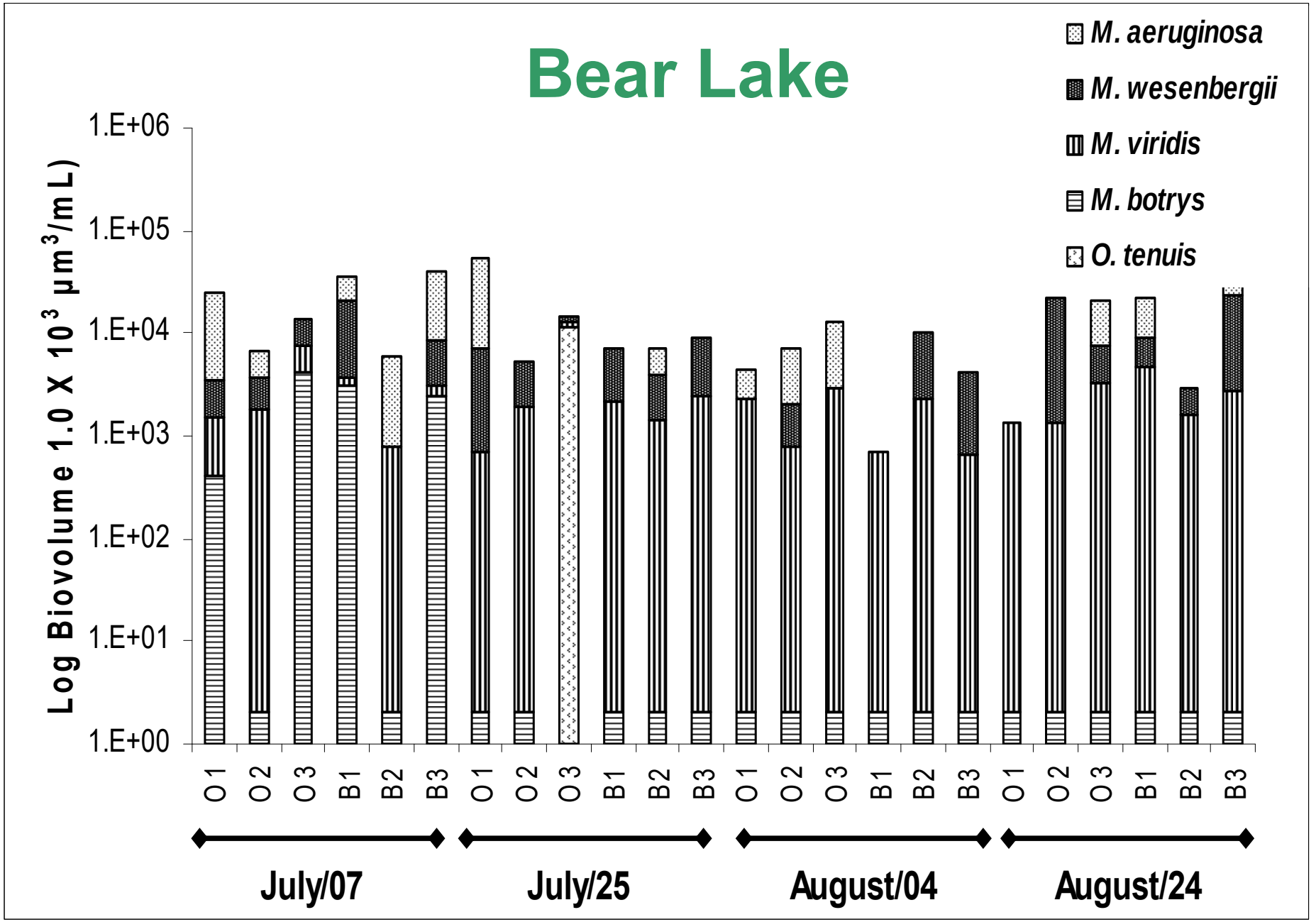
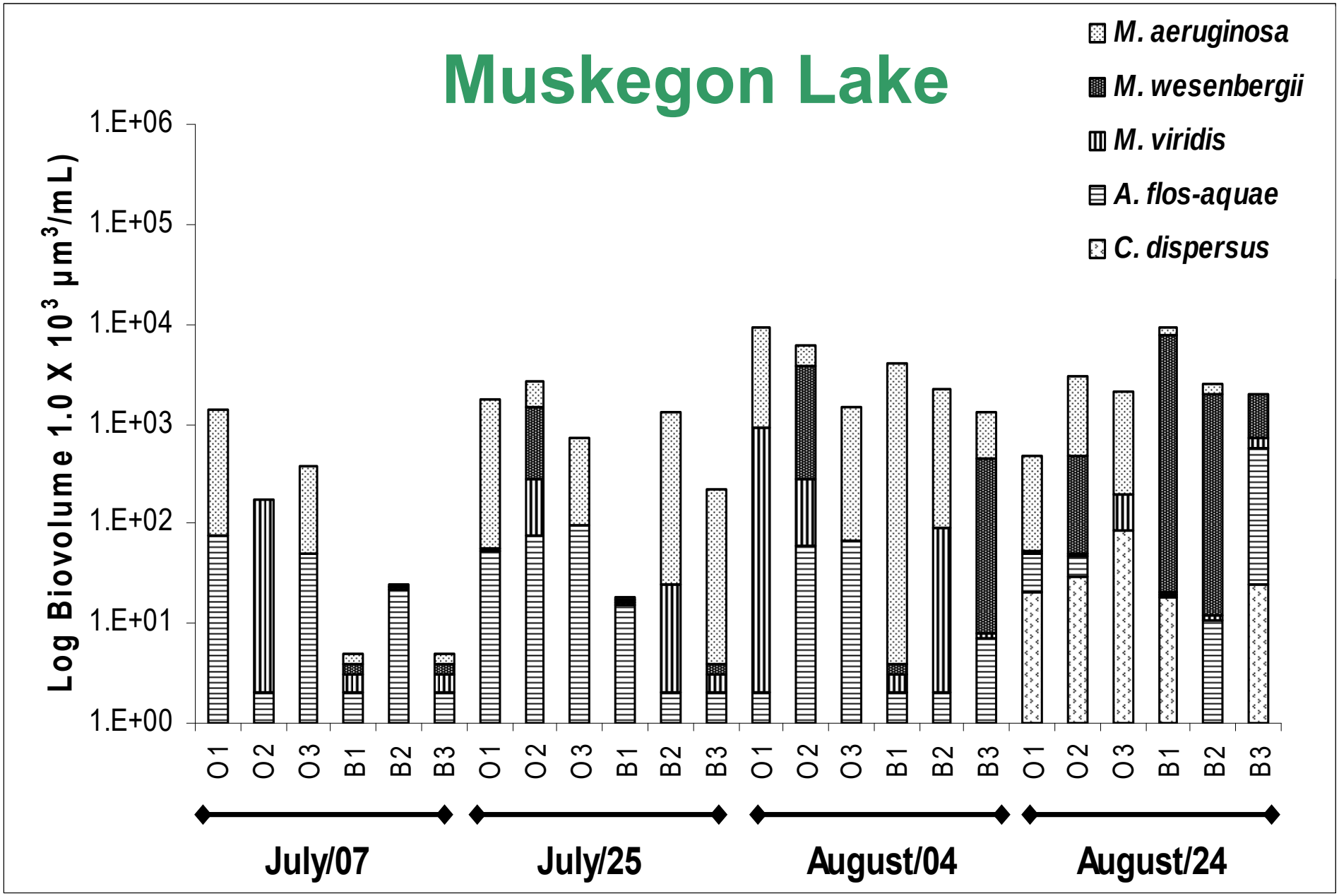
Thank you!



Xie et al. 2011



Xie et al. 2011

Cylindrospermopsis raciborskii (trichomes/ml)